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Assessment of Corona/Arcing Hazard for Electron Beam Welding in Space Shuttle Bay at LEO for ISWE: Test Results

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

TECHNICAL MEMORANDUM

ASSESSMENT OF CORONA/ARCING HAZARD FOR ELECTRON BEAM WELDING IN SPACE SHUTTLE BAY AT LEO FOR ISWE: TEST RESULTS

INTRODUCTION: WHY THIS STUDY WAS UNDERTAKEN

This study was undertaken to ensure that no hazard would exist from unwanted electrical discharges, i.e., arcing or corona, during the electron beam welding exercise required for the International Space Welding Experiment (ISWE).

Welding carried out as early as 1984 by the Soviets with the Ukrainian Universal (Electric Beam Welding) Hand Tool (UHT) do not seem to have resulted in any unwanted electrical discharges. There have been no reports of such. The body of the UHT is grounded, and high voltages are restricted to the filament region inside the UHT body.

The only arcing encountered in commercial electron beam welding takes place inside the electron beam gun in the region between the high-voltage filament and the grounded accelerating anode. Should this take place, commercial equipment has circuitry to detect it and to shut off the beam power.

It is possible, however, that the pressure in the enclosed space shuttle bay may be higher than that encountered by the Soviets in their extravehicular activity (EVA) welding experiment. Gas pressure measurements made on space shuttle mission STS–39 yielded typical pressures of around 10^{-6} torr, with fluctuations to around 10^{-4} torr.[1] It was calculated that the leakage from a space suit, or extravehicular mobility unit (EMU), could produce a pressure rise to 10^{-4} torr in the neighborhood of the UHT.

Because of the potentially higher pressures to be encountered in the shuttle bay in proximity to a leaky EMU, it was deemed advisable to operate the UHT under higher pressures than anticipated to see whether any signs of unwanted or dangerous electrical discharges would be observed.

PLAN OF THE EXPERIMENT

A range of pressures starting from within the normal UHT operating range below 10^{-4} torr (depending upon the capability of the vacuum chamber) and rising to 10^{-3} torr, an order of magnitude above the highest anticipated pressure level, was selected.

Argon gas was used to pressurize the chamber because of oxygen’s detrimental effect on diffusion pumps and apparatus in the vacuum chamber. A precedent for the use of argon to test for arcing potential has already been set by tether arcing simulation studies. The following brief discussion of the physics underlying the beginning of electrical discharges explains why argon may be substituted for air with no substantial loss of verisimilitude and points out the factors limiting incipient discharges. Only the initiation of discharges is discussed and not the more complicated subsequent developments of intensification, sustainment, etc.

Electrical discharge processes start when an electron emitted from a surface or from a gas atom (caused by, say, the impact of a random photon) picks up enough energy from the ambient electric field to produce more electrons when it collides with a gas atom in its vicinity. The newly emitted electrons produce still more electrons in subsequent collisions and induce an avalanche of electrons. At sufficiently high pressures (dependent upon the ambient electric field), discharges do not occur because the electron mean free path between collisions is too short for the electron to pick up enough energy between collisions to cause the emission of electrons. This situation is not of concern here.

At sufficiently low voltage, below the “minimum sparking potential,” electrical discharges do not occur at any pressure. The minimum sparking potential has to be above the ionization potential of the gas. The ionization potentials of oxygen and nitrogen are 14.5 and 13.6 V, respectively, and the minimum sparking potential of air is around 275 V. “Thus, for example, *a spark will not pass below about 275 V in air, no matter what the conditions*. Similar values hold for other gases, being lowest for the inert ones, especially when slightly impure, such as He or Ne with A or Hg present, and for electrodes of low work function.”[2]

The ionization potential of argon is 15.8 V, a bit above but not far from that for nitrogen and oxygen, so it is not surprising that a similar minimum sparking potential is reported. Note that the electrode, which emits a spark, also has an effect upon the minimum sparking potential, because secondary electrons are emitted from the electrode as well as from the gas due to the action of impinging ions. Here, however, the 8,000 V potential level exceeds the 275 V minimum sparking potential so greatly that the mechanism of ionization is not of great concern.

At sufficiently low pressures, electrical discharges do not occur because there are not enough available atoms to collide with. Given a voltage V acting across a gap distance d, a discharge cannot occur if the pressure P of the gas in the gap is so low that the mean free path λ of the gas atoms is greater than the gap width d. Given a collision cross section σ with a particular gas (on the order of πr^2, where r is the radius of a monatomic gas atom) an electron sweeps a volume $\sigma\lambda$ between collisions. The swept volume between collisions should be the same as the volume occupied by a single gas atom, approximately kT/P, where k is Boltzmann’s constant; T, the absolute temperature; and P, the pressure of the gas. Thus, λ is found to be $kT/\sigma P$, and hence an electrical discharge should not occur unless d is greater than $kT/\sigma P$ or Pd is greater than kT/σ. For nitrogen the approximate atomic radius is 1.06×10^{-10} m;[3] 0.25×10^{-10} m if singly ionized to the +1 state.[4] Oxygen ionized to +1 has an approximate radius of 0.22×10^{-10} m and 1.76×10^{-10} m in the –1 state. Argon has an approximate atomic radius of 1.9×10^{-10} m and 1.54×10^{-10} m in the +1 ionized state. Since the smaller Pd, the greater the likelihood of an electrical discharge, argon appears to be more likely to show a discharge than air. It may be added that given the use of laboratory temperatures rather than the higher temperatures of the atmosphere at Low Earth Orbit (LEO), the present test appears still more conservative. Thus, argon gas is deemed a conservative equivalent to air for the purpose of modeling electrical discharge behavior.

The power current to the tool (I_{POWER}) and the tool cathode current from ground (I_{TOOL}) and the sample current (I_{SAMPLE}) to ground as designated in figure 1 were measured by magnetic flux current sensors around the lines.

The current to the tool cathode comprises I_{TOOL} from the power supply and a ground return via metal-to-metal contact with the vacuum chamber wall. The bulk of the cathode current is emitted from the UHT as the electron beam with the exception of anode and chamber wall losses. The anode losses are caught on the anode of the UHT, where they are available for recycling to the cathode after giving up their heat to the UHT anode. The beam impinges on the weld sample and leaks off to ground as I_{SAMPLE}, except for the fraction of the beam which is backscattered to the UHT case/anode.

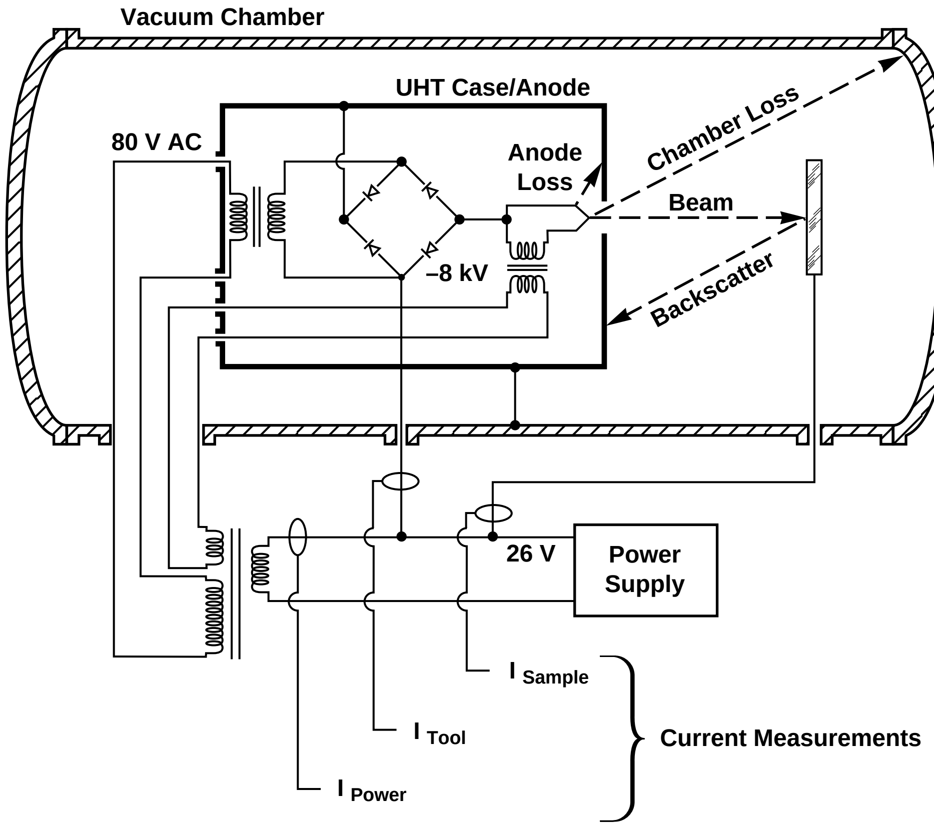

Figure 1. Simplified UHT power circuit showing current measurement sites.

EXPERIMENTAL RESULTS

Measurements of I_{POWER}, I_{SAMPLE}, and I_{TOOL} taken for six runs are tabulated in table 1.

Table 1. Measured currents.

Run	Pressure (torr)	Material	Power Current (I_{POWER}) (A)	Sample Current (I_{SAMPLE}) (mA)	Tool Current (I_{TOOL}) (mA)
3	2.4×10^{-4}	5456	36	65	70
5	1.7×10^{-4}	6-4-Ti	?	40	45
6	1.7×10^{-4}	304SS	32	58	60
13	1×10^{-3}	304SS	31	53	55
14	1×10^{-3}	6-4-Ti	?	40	45
15	1×10^{-3}	5456	36	60	63

The question marks in table 1 indicate the absence of a readable line on the oscilloscope. The associated power current values are assumed similar to the other values.

A typical run curve is shown in figure 2.

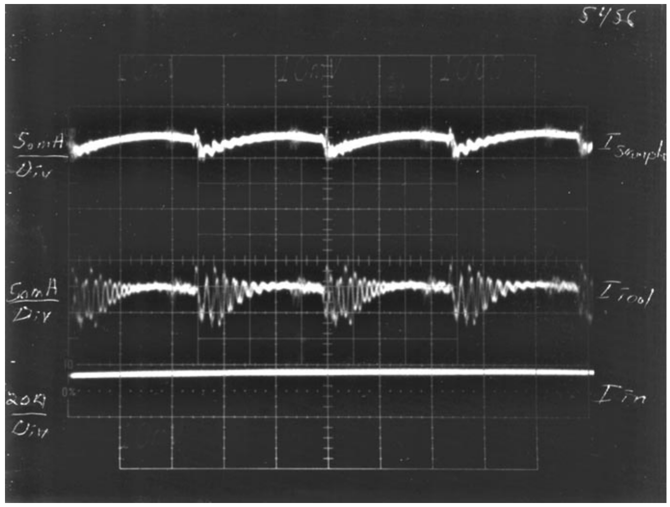

Figure 2. Sample current, I_{SAMPLE} (upper curve), tool cathode current, I_{TOOL} (middle curve), and power supply current, I_{POWER} (bottom curve) for run 3.

No spikes indicating arcing were observed.

The total test matrix is shown in table 2.

Table 2. Test matrix.

Run	Vacuum Level (torr)	Plasma Environment	Power Mode	Material	Arcing
1	1.7×10^{-4}	Yes	5	5456	No
2	1.7×10^{-4}	Yes	6	5456	No
3	2.4×10^{-4}	Yes	6	5456	No
4	1.7×10^{-4}	Yes	4	6-4-Ti	No
5	1.7×10^{-4}	Yes	4	6-4-Ti	No
6	1.7×10^{-4}	Yes	5	304SS	No
7	1.5×10^{-5}	No	6	5456	No
8	1.9×10^{-5}	No	4	6-4-Ti	No
9	1.9×10^{-5}	No	5	304SS	No
10	1.2×10^{-4}	No	5	304SS	No
11	1.4×10^{-4}	No	4	6-4-Ti	No
12	1.1×10^{-4}	No	6	5456	No
13	1×10^{-3}	Yes	5	304SS	No
14	1×10^{-3}	Yes	4	6-4-Ti	No
15	1×10^{-3}	Yes	6	5456	No

Although no discharges were seen, a faint glow (generally blue, but green in the case of the stainless steel samples and in one instance near the beam impingement point on the 5456 sample) of excited atoms was seen in the vicinity of the beam. The glow was stronger along the beam path and exhibited a fainter parabolic sheath around the beam. The tip of the parabola was located on the beam impingement point on the sample. In one instance (5456 aluminum at 1.1×10^{-4} torr with no plasma), the glow expanded to fill the chamber. The glow was very steady in character and showed no tendency to oscillate or waver.

INTERPRETATION OF RESULTS

The electrical currents measured are all of reasonable magnitude and, with the exception of some minor oscillations normal for rectified ac currents, steady. No current spiking phenomena indicative of electrical discharges were observed.

No visual indications (for example, flashes or bright local clouds) of arcing or corona discharges were to be seen in the chamber.

The faint “glow” (“glow” is used here in a general descriptive sense) observed in the vicinity of the electron beam is not a “corona discharge” or a “glow discharge” (here the term “glow” is used in a technical sense referring to a specific phenomenon). A corona discharge is (at lower currents and higher voltages) essentially the same as a “glow discharge” in a low-pressure electronic tube. A corona or glow discharge represents light emitted from atoms excited by the electrical discharge. Both types of discharge exhibit light spaces and dark spaces that depend upon the amount of energy the electrons have picked up from the driving electric field and the kinds of collisions they are having at various positions along the discharge. A corona (the name means “crown” or “garland” and ultimately derives from an Indo-European root **sker*—meaning to turn or bend) is a local (and hence bent rather than straight-line) electrical discharge, where the local electric field is large enough to accelerate electrons to a point where they can cause local electron avalanches in the available atmosphere. The ions and electrons generated in a corona discharge flow away in opposite directions. One carrier flows out and carries the discharge current to ground without generation of further current. The other carrier flows back into the corona to carry the current to its source.

The observed glow may be interpreted as due to atoms made to radiate visible light by excitation in the electron beam. There is both a backfill of argon atoms and an evaporant from the weld pool present in the beam chamber. Some of these atoms flow through the beam and are excited by electronic collisions in the beam. This is why a relatively bright glow emanates from along the electron beam path. The excited atoms that emerge from the beam path form the fainter parabolic glowing sheath around the beam. Changes in the color and the extent of the glow are a result of changes in the character of evaporant from the metal surface. This glow from optically excited atoms does not represent a dangerous or potentially dangerous discharge.

Thus, at pressures substantially above those anticipated for welding during the ISWE and at ionization levels comparable to those at LEO, no electrical discharges carrying measurable current were encountered.

CONCLUSIONS

The results of this study indicate that the Ukrainian Universal Hand Tool presents no danger with respect to unwanted arcing or corona electrical discharges.

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Test welds were made in argon over a range of pressures from 10^{-5} to 10^{-3} torr (the latter pressure an order of magnitude above pressures anticipated in the space shuttle bay during welding) with and without plasma on 304 stainless steel, 6Al-4V titanium, and 5456 aluminum in search of any possible unwanted electrical discharges. Only a faint steady glow of beam-excited atoms around the electron beam and sometimes extending out into the vacuum chamber was observed. No signs of current spiking or of any potentially dangerous electrical discharge were found.

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